DOCUMENT RESUME

ED 347 334 CE 061 564

AUTHOR	Luthens, Roger
TITLE	Structural Science Laboratory Supplement. High-Technology Training Module.
INSTITUTION	Wisconsin Indianhead Technical Coll., Rice Lake.
SPONS AGENCY	Office of Vocational and Adult Education (ED), Washington, DC.
PUB DATE	10 Apr 90
CONTRACT	V199A90151
NOTE	43p.; Developed as part of the High-Technology Training Model for Rural Based Business and Industry, Technical Colleges and Local and State Educational Agencies.
PUB TYPE	Guides - Classroom Use - Teaching Guides (For Teacher) (052)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	*Building Design; *Construction Materials; Laboratory Experiments; Learning Modules; *Structural Building Systems; Technical Education; *Technological Advancement; Two Year Colleges
IDENTIFIERS	Technology Education

ABSTRACT

This module, a laboratory supplement on the theory of bending and properties of sections, is part of a first-year, postsecondary structural science technical support course for architectural drafting and design. The first part of this two-part supplement is directed at the instructor and includes the following sections: program objectives; course description and objectives; course outline; module goal, objectives, and sequence; module content outline; instructor methodology and time frame; and evaluation. The course outline contains the following units: forces and stresses; reactions; shear and bending moments; theory of bending and properties of sections; and trusses. The second part of the supplement is a student packet that includes the following sections: student objectives; student requirement and timeline; student resources; elastic modulus lab activity; and beam deflection lab activity. Appendices contain the pre- and postmodule assessment instrument, equipment notes, six references, and results of equipment trials. (NLA)

High-Technology Training Module

Module Title: STRUCTURAL SCIENCE LABORATORY SUPPLEMENT

Unit: THEORY OF BENDING AND PROPERTIES OF SECTIONS

Course: STRUCTURAL SCIENCE (Technical Support Course)

Grade Level (s): POSTSECONDARY

Developed by: ROGER LUTHENS

Date: APRIL 10, 1990

School: WISCONSIN INDIANHEAD TECHNICAL COLLEGE

1900 COLLEGE DRIVE, RICE LAKE, WI 54868

In Touch with High Tech

Developed as a part of the High-Technology Training Model for Rural Based Business and Industry, Technical Colleges and Local and State Educational Agencies under Grant No. V199A90151.

Table of Contents

Structural Science Laboratory Supplement

Module Title: Laboratory Supplement for Structural Science

Program Level: Technical College
Associate Degree
Architectural Design

Program Mission: The mission of the two year Associate Degree program in Architectural Design is to prepare post-secondary students for architectural drafting and design at entry level positions.

Program Objectives:

1. To give students entry level skills in residential and commercial drafting.

2. To give students basic principles of material strength and structural design.

Course Title: Structural Science

Course Level:

1. Technical support

2. Second semester of first year

Course Description:

Refer to the course description and outline on the following two pages.

C806125CO/APRFTCOURS/QTXT

WISCONSIN INDIANHEAD VTAE DISTRICT
Course Description/Outline

12/15/88

COURSE TITLE	Structural Science			
COURSE NUMBER	10-806-125	CLASSROOM PRESENTATIONS	(A)	36.00
SEMESTER HOURS	72	LAB/CLINICAL/SHOP EXPERIENCE	(B)	36.00
CREDITS	3.00	INDIVIDUAL/INDEPENDENT INSTRUCTION	(C)	
CEU'S		SIMULATED/ACTUAL OCCUPATIONAL EXP	(D)	
CEC'S		ON-THE-JOB EXPERIENCE	(E)	

COURSE DESCRIPTION:

Basic physical concepts of structural mechanics, external stresses and internal reactions, in beams, columns and trusses are studied and applied to practical problems supported with lab activities. (PREREQUISITES: 804-141 Technical Math I.)

COURSE COMPETENCIES:

Upon successful completion of this course, the student in accordance with the grading standards will be able to:

1. Solve practical problems dealing with external forces, reactions, shear, and moments.
2. Solve problems involving the theory of bending and properties of sections.
3. Solve basic truss analysis problems.
4. Utilize related association and manufacturers handbooks and data in the solution of structural mechanics problems.
5. Communicate with professionals in the trade using correct nomenclature.

PREPARED BY: Roger Luthens
COORD. APPROVAL: George Pratt
DISTRICT APPROVAL: Lois L. Eichman
SUBMITTED BY: William Rhiger
DATE: 4/87
REVISED: 7/24/87
DATE: 11/20/87

COURSE OUTLINE BY UNITS:

	TYPE OF HOURS A	B
I. Forces and Stresses	5.00	5.00
A. Forces		
B. Stresses		
C. Hookes Law		
D. Elastic limit		
E. Ultimate strength		
F. Unit stress		
G. Deformation		
H. Modulus of Elasticity		
II. Reactions	7.00	7.00
A. Types of beams		
B. Loads		
C. Reactions		
D. Distributed load calculations		
E. Overhanging beam calculations		
III. Shear and Bending Moments	11.00	11.00
A. Vertical Shear		
B. Bending moments		
C. Shear and moment diagrams		
D. Cantilevered beams		
E. Typical loading formulas		
IV. Theory of Bending and Properties of Sections	7.00	7.00
A. Flexure formula		
B. Centroids		
C. Section modules		
D. Radius of gyration		
V. Trusses	6.00	6.00
A. Related principles of Trigonometry		
B. Loads		
C. Internal forces		
D. Analysis and design of trusses		
E. Selection of members		
F. Joint design		
Totals	36.00	36.00

RECOMMENDED/SUGGESTED TEXTS & MATERIALS:

Structural Engineering for Architects and Builders, 6th Ed. by Parker and Ambrose, John Wiley and Sons, 1984

Module Goal: The goal of this module is to provide students with physical science laboratory experience related to structural design.

Objectives: After completing the module, it is expected that the student will be able to:

1. Determine by laboratory experiment the numerical value of the elastic modulus of a small metal sample.

2. Use a laboratory exercise to further learn and reinforce concepts of beam design.

3. Develop understanding of the role of physical science in applied science.

4. Observe the relationship between theory and experimental design.

5. Observe and use indirect measurement.

6. Develop individual and group skill in the manipulation of equipment and gathering of data.

7. Use theory and data to develop results and reasonable conclusions.

Sequence: The first laboratory exercise in this module can be used as part of Unit I of the course outline. (See previous two pages.)
The second laboratory exercise should be used following an introduction to the concepts in Unit IV. Alternately, both exercises could be used in conjunction with Unit IV as both involve concepts that are used in the unit; in addition, both exercises use similar measuring techniques.

Module Content Outline

A. Student objectives

B. Student requirements

C. Student resources
   1. Elastic modulus determination
   2. Beam deflection experiment

D. Elastic modulus determination
   1. Purpose
   2. Theory
   3. Procedure
   4. Data collection
   5. Results
   6. Conclusions
   7. Review questions

E. Beam deflection experiment
   1. Purpose
   2. Theory
   3. Procedure
   4. Data collection
   5. Results
   6. Conclusions
   7. Review questions

Instructor Time Framework:

Suggested time frame is to allow two hours for completion of each of the two laboratory exercises in this module. This would allow ample time for data collection, calculations and completion of conclusions. Note that since the purpose of the module is to provide reinforcing lab experience, it is felt that nothing would be gained by having students spend time with equipment set up and adjustments. It is felt that the instructor should have equipment set up and fine-tuned.

Instructor Methodology:

1. Short introduction to lab exercises
   a. Limit to ten minutes at most.
   b. Concentrate on tips for maximum utilization of measurement potential of equipemnt.
2. Set up and adjust equipment.
3. Serve as resource person in lab.
4. Encourage group interaction.
   a. Suggested three students per lab group.
5. Question results and conclusions.

Module Evaluation:

Student requirements and evaluation criteria are as follows:

A. Pre-module survey

B. Complete two laboratory experiments including following:

   1. Read theory
   2. Follow lab procedures
   3. Record data
   4. Perform calculations
   5. Analyze results
   6. State conclusions
   7. Complete summary questions
   8. Hand in items 3-7

C. Post-module survey

D. Item B-8 (above)

   1. Lab reports will be graded on a 20 point basis; scores will be included in the laboratory component of the course grade.
   2. Laboratory component constitutes 30% of course grade.
   3. Grading standards for course:

      93% = A

      85% = B

      70% = C

      60% = D

      <60% = F

Student Objectives

To the student:

The package you have received contains two laboratory exercises. The goal of both of these exercises is to have you experience the relationship between physical science and basic design concepts. In achieving this goal you will also reinforce design concepts that you have been learning by other methods. When you have completed the lab exercises, you should be able to:

1. Calculate the value of the elastic modulus of a small metal sample from laboratory data.
2. Test beam flexure theory by doing calculations based on lab data.
3. Explain relationships between theory and experiment design.
4. Explain indirect measurement and the necessity of using this technique in some lab situations.
5. Develop experimental and data gathering skills.
6. Use data to develop results and conclusions.
7. Rely on group as well as individual work to help in achieving the objectives of the exercises.

Module Timeline

and

Requirements

This module requires you to complete two laboratory experiments. The experiments may be assigned sequentially or at different points in the course; in either case, you will be issued duplicate copies of any pages that must be handed in so the packet may be kept intact. The time required for each lab exercise should be no more than a two hour lab period from start to finish. In addition to the requirements listed below, you will be asked to complete a short pre-survey prior to the first exercise and short post-surveys following the completion of each exercise. The pre and post-surveys will not be graded and should require only several minutes to complete. Each lab follows the same basic format; the parts of each exercise that have to be handed in are underlined below. The lab report that you hand in for each of the two experiments will be graded on a 20 point basis and the score will be added to the laboratory component of the course. You will be graded on the basis of completeness, results and conclusions appropriately based on data and on thoughtful responses to the review questions.

A. Laboratory Exercise:
Elastic Modulus of a Metal

1. Purpose (reading)
2. Theory (reading)
3. Procedure
4. <u>Data</u>
5. <u>Calculations and results</u>
6. <u>Conclusions</u>
7. <u>Review questions</u>

B. Laboratory Exercise:
Beam Deflection

1. Purpose (reading)
2. Theory (reading)
3. Procedure
4. <u>Data</u>
5. <u>Calculations and results</u>
6. <u>Conclusions</u>
7. <u>Review questions</u>

Student Resources

A. Elastic Modulus Determination

1. Text: Simplified Engineering for Architects and Builders, 7th Ed. by Parker and Ambrose, Wiley and Sons, 1989

2. Supplementary references: Almost any introductory technical or applied physics text or any introductory statics and strength of materials text should contain supplementary reading; there are at least six good references available in the lab area.

3. Lab packet and duplicates of pages to be handed in are provided.

4. Equipment as schematically shown in the experiment write-ups will be set up by the instructor.

B. Beam Deflection

1. All items are the same as above.

Laboratory Exercise

Elastic Modulus of a Metal

PURPOSE: The purpose of this exercise is to reinforce the concepts of stress, strain and elastic modulus and to determine by measurement the numerical value of the elastic modulus of a thin sample of metal.

THEORY: In any type of design work whether it be structural or mechanical whenever it is necessary to take into account the flexibility of a material, the concept of elastic modulus is certain to be involved. As a starting point, please note that the modulus of elasticity of a material should be viewed as a relative measure of the flexibility of a material and by itself is not a measure of any of the allowable working stresses of the material.

Any material when subject to a loading force is said to be in a state of stress. Stress is defined as the ratio of force applied to the cross-sectional area on which the force acts. Symbolically:

Formula 1: $f = \frac{P}{A}$ where P = force (lb)
A = cross-sectional area (sq in)
f = stress (lb/sq in)

When undergoing stress, all materials react by changing shape and are said to be under strain. Strain is defined as the ratio of the change in shape to the original shape. The concepts of stress and strain in this exercise apply only to axial stresses which may be either tensile or compressive; more specifically, only tensile stress and strain will be dealt with. Since tensile strain is being dealt with, for this exercise strain may be defined as the ratio of length change to original length. Symbolically:

Formula 2: $s = \frac{e}{L}$ where e = change in length (in)
L = original length (in)
s = strain (in/in or actually a dimensionless unit)

THEORY: (continued)

All materials possess a property known as elasticity. Elasticity refers to the ability of a material to be stressed and return to original shape after the stress is removed. The point at which a material would no longer return to shape if additional stress is applied is known as the elastic limit of the material. For most metals the elastic limit is a fairly distinct stress value and many metals even retain ability to withstand loads after the elastic limit has been reached. For some materials, especially those that are brittle such as cast iron, the elastic limit and the breaking stress occur almost simultaneously. Whatever the material, as long as the elastic limit has not been exceeded, strain is directly proportional to stress. Another way of stating this is that the ratio of stress to strain is a constant value which is known as the elastic modulus of the material. Symbolically:

Formula 3: $E = \frac{f}{s}$ or substituting from

formulas 1 and 2 on the previous page:

Formula 4: $E = \frac{PL}{eA}$ where P, L, e and A are the same as on the previous page and E = elastic modulus (lb/sq in)

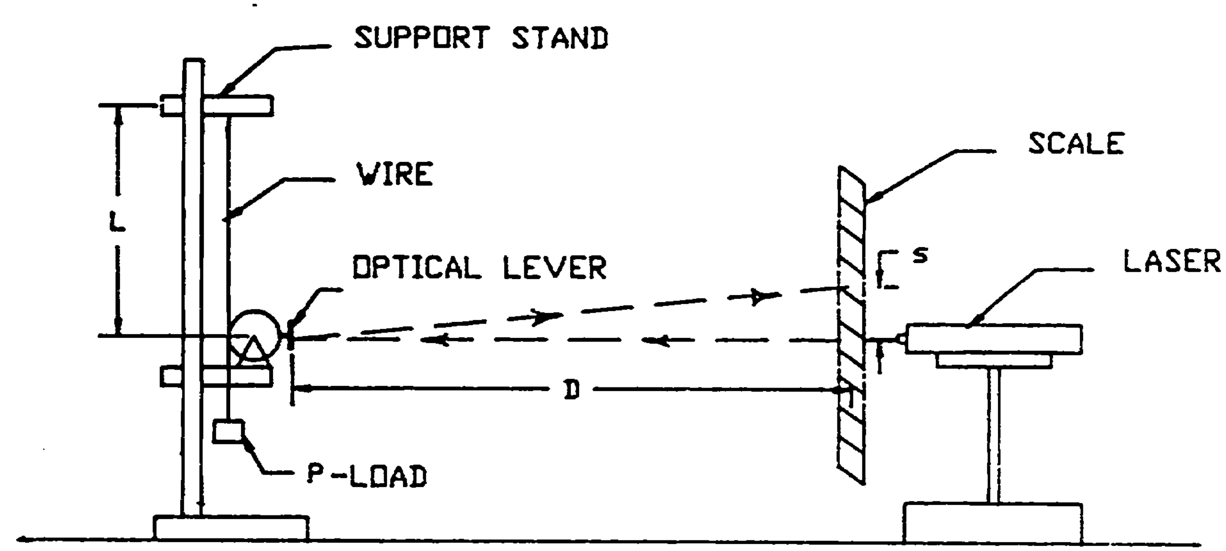
Note that the unit of measurement for the elastic modulus in the U.S. system of measurement is lb/sq in (sometimes abbreviated psi). The reason for the unit which appears to be the same as a stress rating of the material is apparent from the definition of strain and formula 3 above. Perhaps it would be helpful to keep in mind that the dimensionless number which represents strain has a unit of inches/inches and that elastic modulus represents pounds per square inch per unit of tensile strain. This again avoids confusing elastic modulus with an allowable stress rating of a material.

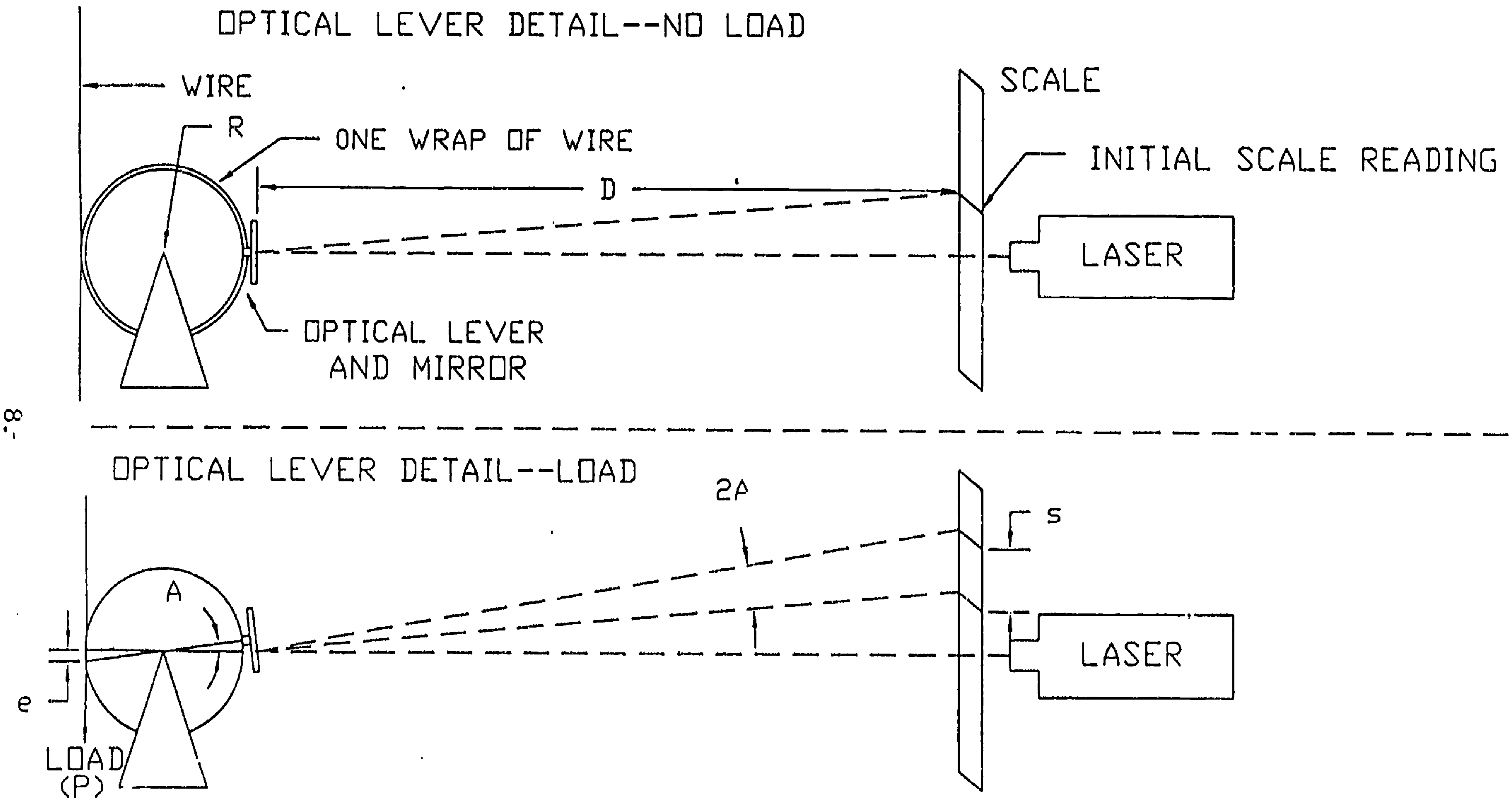
THEORY: (continued)

There are several methods for determining the elastic modulus of a material. One method makes use of hydraulic or mechanical equipment which exerts large forces on a sample that might have a diameter of ¼ inch or larger. This method might be used in an industrial testing laboratory; however the basic principles can be illustrated by using less costly equipment in a physics laboratory. The equipment used in this lab exercise makes use of light loads up to a maximum a a few pounds. The major problem in the use of this equipment is that a light wire must be used instead of a bulk sample of metal and that even industrial testing laboratories many times report inconsistent values for the elastic modulus of thin samples. There may be a number of reasons for these inconsistencies such a varying temperatures or work hardening under stress; so care must be taken in reporting the elastic modulus of a small sample of any material. A second problem in measuring E for a material is that the strain is small and difficult to measure directly. In this lab you will use a piece of equipment called a Fitch optical lever which allows you to amplify the stretch of the wire by using a reflected laser beam. This is an example of using an indirect measurement. Indirect measurement is the process of measuring a quantity which is impractical or impossible to apply a measuring instrument to by measuring another quantity which is easier to measure.

In the explanation of the optical lever and how it relates to the theory of this experiment, please refer to the schematic diagram on the following two pages. The optical lever is a small cylinder which is free to rotate on bearings about its central axis. Attached to the cylinder is a small mirror which will rotate through any angle that the cylinder is rotated. A laser is located at some distance from the mirror and positioned so the laser beam reflects off the mirror back on to a scale located next to the laser. By a basic principle of optics, if a mirror rotates through an angle, a beam of light striking the mirror will be reflected at an angle that is twice as large.

SCHEMATIC--ELASTIC MODULUS APPARATUS




OPTICAL LEVER DETAIL--NO LOAD
WIRE
R
ONE WRAP OF WIRE
D
SCALE
INITIAL SCALE READING
LASER
OPTICAL LEVER
AND MIRROR
OPTICAL LEVER DETAIL--LOAD
2A
S
A
LASER
e
LOAD
(P)

THEORY: (continued)

If the sample wire to be tested is wrapped firmly around the cylinder and a load is applied to the end of the wire below the cylinder, the wire will stretch between its upper support and the cylinder center by an amount e and the circumference of the cylinder will also rotate by the same amount e. The radius, R, of the cylinder will rotate through an angle designated as A. From the definition of radian measure of an angle which is arc divided by radius:

Formula 5: $A = \frac{e}{R}$

The reflected laser beam strikes the measuring scale at some initial zero point. This does not actually have to be zero but is simply a reference point for subsequent readings after a load is applied. The distance from the initial zero point on the scale to the front of the mirror of the optical lever is designated as D. When the load is applied, D may be visualized as rotating through an angle 2A about a vertex located at the mirror surface. As the beam is rotated, the reflection on the measuring scale moves through a distance s. To be mathematically correct, the scale should be a circular arc of radius D; however, since the stretch of the wire is very small, the angle through which the beam turns is also small and a quick mathematical check shows that distance s on the measuring scale would approximate the arc of a circle to within a small fraction of a percent. So, by again using the definition of radian measure:

Formula 6: $2A = \frac{s}{D}$ or $A = \frac{s}{2D}$

Combining formulas 5 and 6 above gives:

Formula 7: $e = \frac{Rs}{2D}$

THEORY: (continued)

The optical lever then has supplied a method of measuring the elongation of the wire in terms of other quantities that are easier to measure. Substituting the right hand side of formula 7 into formula 4 gives the final working formula for this lab:

Formula 8: $E = \frac{2PLD}{rsA}$

The variables on the right hand side of formula 8 are the quantities that must be measured in the lab in order to determine the value of E and they are once again summarized below along with the units of measurement in which they must be expressed.

P = load applied to wire (lb)

L = length of wire being stretched (in)

D = distance from front of mirror on optical lever to zero point on measuring scale (in)

r = radius of cylinder on optical lever (in)

s = distance between zero reading on measuring scale and deflected reading after applying load (in)

A = cross-sectional area of wire (sq in)

E = elastic modulus of wire (lb/sq in)

PROCEDURE:

The equipment should be set up and adjusted before the class; however, if you need to set up and adjust the equipment, the following are suggestions:

1. Place the laser and measuring scale at a distance of approximately 2 meters from the apparatus supporting the wire and optical lever.

2. Adjust the height and horizontal position of the stand supporting the laser until the beam is reflected back to the measuring scale. The scale should be vertical and as close as possible to the laser. You may also adjust the mirror so the reflected beam strikes the measuring scale at the same approximate height as the outgoing beam.

PROCEDURE: (continued)

3. Caution: Even though the laser is low power, avoid looking directly at the emerging beam or the beam reflected from the mirror.

4. After you have made the initial adjustments above, you can further narrow the reflected beam by placing a ray condensing lens directly over the laser aperature. Adjust the lens in the center of the beam until you see a narrow band of laser light reflected on the measuring scale.

5. Several precautions must be taken when measuring the elongation of the wire. First, you wish to measure only the stretch of the wire so it must be free of small kinks and should be tightly wrapped around the optical lever cylinder. To maintain tension on the wire, place a small weight on the hanger.(1 kg should be sufficient.) To be sure that the wire is stretching and elastically returning to its original length, alternately place and remove another 1 kg weight on the hanger. Observe that the reflected beam is returning to the same position on the scale each time you place a weight on the hanger and each time you remove the weight from the hanger.

6. You must be satisfied that you have completed step 5; if you are unable to stabilize the apparatus so that the beam deflects when a weight is placed on the hanger and returns to its original position when the weight is removed, ask the instructor for additional suggestions. If you are now certain that step 5 has been completed, you are ready to begin taking data. From this point on, be careful not to move or even slightly jar any of the apparatus or you will have to discard your data.

7. Record the initial scale reading and place a load on the weight hanger. Any load from 2 to 5 kg will be adequate. Record the deflected scale reading. Once again remove and replace the load several times to be certain you are reading a consistent deflection on the measuring scale.

PROCEDURE: (continued)

8. Measure and record the other quantities needed to complete your data.
9. Complete the entire procedure using a different kind of wire.
10. Complete the calculations, results and questions.

DATA:

Trial 1

Type of wire ____________

P = _________ g = _________ lb (1 g = .0022 lb)

L = _________ in

D = _________ in

r = _________ in

s = _________ cm = _________ in (1 cm = .3937 in)

d = diameter of wire = _________ in

A = .7854(d^2) = _________ sq in

Trial 2

Type of wire ____________

P = _________ g = _________ lb

L = _________ in

D = _________ in

r = _________ in

s = _________ cm = _________ in

d = _________ in

A = _________ sq in

CALCULATIONS:

Calculate the value of E for both types of wire by using the working formula derived in the theory.

Trial 1

E = ____________________ lb/sq in

Trial 2

E = ____________________ lb/sq in

RESULTS and CONCLUSIONS:

Results such as you have calculated are meaningful only if they are repeatable and within the margin of equipment capability. An exact mathematical analysis of experimental results is beyond the background of this course; so you will be asked to take an oversimplified and somewhat pessimistic approach to analyzing your results. The instructor has determined that the combination of measurement uncertainties in the equipment used leads to an overall uncertainty of slightly less than ± 10% in the final calculation. In other words, no matter how careful you are in manipulation of equipment and measuring instruments, due to the inherent uncertainty of the measurement process, you could be certain of the precision of the final answer only within 10%.

RESULTS and CONCLUSIONS: (continued)

In analyzing the repeatability of your results, gather the results from the other groups in the class and average all of these final results. Determine the percentage of variation of your results from the class average. Your result should be reported as being within that percentage of the average results.

Class Results:

E--Trial 1	E--Trial 2
______________	______________
______________	______________
______________	______________
______________	______________
______________	______________
______________	______________

Average: ____________ psi ______________ psi

Comparison of results:

Determine the absolute value of the difference between your results and the class average for both trials and express this as a percent of the average.

Trial 1

$$\frac{\text{Difference}}{\text{Average}} = \_\_\_\_\_\_\_\_ \%$$

Trial 2

$$\frac{\text{Difference}}{\text{Average}} = \_\_\_\_\_\_\_\_ \%$$

Concluding statement:

Write a statement about the value of the elastic modulus of the two metals you tested relating to both the class average and the capability of the equipment.

SUMMARY QUESTIONS:

Answer the following by using the lab exercise you have just completed and/or references listed in the resources.

1. Define in a complete sentence:

   a. Stress

   b. Strain

   c. Elastic limit

   d. Modulus of elasticity

2. Explain in a few sentences the physical significance of the concept of elastic modulus of a material.

3. Explain in a few sentences the process of indirect measurement and when it would be necessary to use this measuring technique.

4. Two pieces of metal have identical dimensions; one is made of typical structural steel, the other is made of aluminum. Both are subject to the same tensile load within the elastic limit. From reference tables determine:

   a. The yield stress of each metal.

   b. Which will elongate the most and what is the approximate ratio of the elongation of the steel compared to the elongation of the aluminum?

Laboratory Exercise

Beam Deflection

PURPOSE:

The purpose of this exercise is to use a laboratory experiment to test a theoretical beam deflection formula and to further reinforce principles of beam flexure.

THEORY:

Deflection of a beam (or any other horizontal support that could be classified as a beam) is defined as the maximum amount of vertical bend in a loaded beam as measured from the unloaded position. There are a number of factors that determine the amount of deflection of a beam:

1. Material (Elastic Modulus)
2. The shape of the cross section (Moment of Inertia)
3. Load (both amount and placement of load)
4. Length between supports
5. Support conditions (whether simply supported, continuous, restrained or cantilevered)

Deflection can be mathematically related to the above factors by means of fomulas for standard load conditions. The general mathematical relationships are as follows: Deflection is inversely proportional to the elastic modulus; a higher value of elastic modulus indicates a stiffer material which bends less. Deflection is also inveresely proportional to the moment of inertia; a higher moment of inertia of a cross section means that the material is more efficiently used and the beam is stiffer. Deflection is directly proportional to load; however a load that is uniformly spread over the length of a beam would produce less deflection than the same load that is concentrated. Deflection is related to length in a rather unexpected mathematical way. Deflection is proportional to the cube of the length between support points. This means for example that if length between support points of a beam is doubled the resulting deflection would be $2^3 = 8$ times as large; it is easy to see that unsupported beam length can be a controlling factor in determining deflection. Deflection formulas have built in constant multipying factors which have been mathematically determined to account for standard load and support conditions.

THEORY: (continued)

In this experiment you will be working with a simply supported beam; this means that the ends rest on supports and are free to rotate when loads are applied. The beam will be made of steel and you may use a value for the elastic modulus of 29.5×10^6 psi. The cross section of the beam will be rectangular and the moment of inertia can be calculated using $\frac{bh^3}{12}$ where b is the length of the side of the cross section which rests on the supports. In the case of one of the model beams which may be used in this exercise, the cross section is a square and the moment of inertia expression simply becomes $\frac{x^4}{12}$ where x is the edge of the square. The load used in this exercise will be a single concentrated load in the middle of the beam. The deflection formula for this type of loading and support condition is:

Formula 1: $d = \frac{PL^3}{48EI}$

The variables of the formula as well as the measurement units are as follows:

P = amount of load (lb)

L = length between supports (in)

E = elastic modulus of steel (psi)

I = moment of inertia of cross section (in^4)

d = deflection at center (in)

In this lab you will make a prediction of the deflection by measuring the quantities on the right hand side of formula 1 and compare this prediction to the actual measured deflection. The measurement of the deflection will again be done indirectly by using the Fitch optical lever with a laser beam. You may wish to review the theory of the optical lever in the lab exercise in which you measured the elastic modulus of metals.

THEORY: (continued)

The formula used to measure the deflection using the optical lever and laser is the same as in the previous lab exercise:

Formula 2: $D = \frac{rs}{2D}$ where r = radius of optical lever (in)
s = measuring scale deflection (in)
D = distance from mirror to measuring scale (in)

Please see the schematic drawing of the equipment for reference to the formulas above.

PROCEDURE:

The following are suggestions to be followed in the event you have to set up the equipment:

1. Place the laser on the adjustable support at least 2 meters from the optical [illegible] and beam.

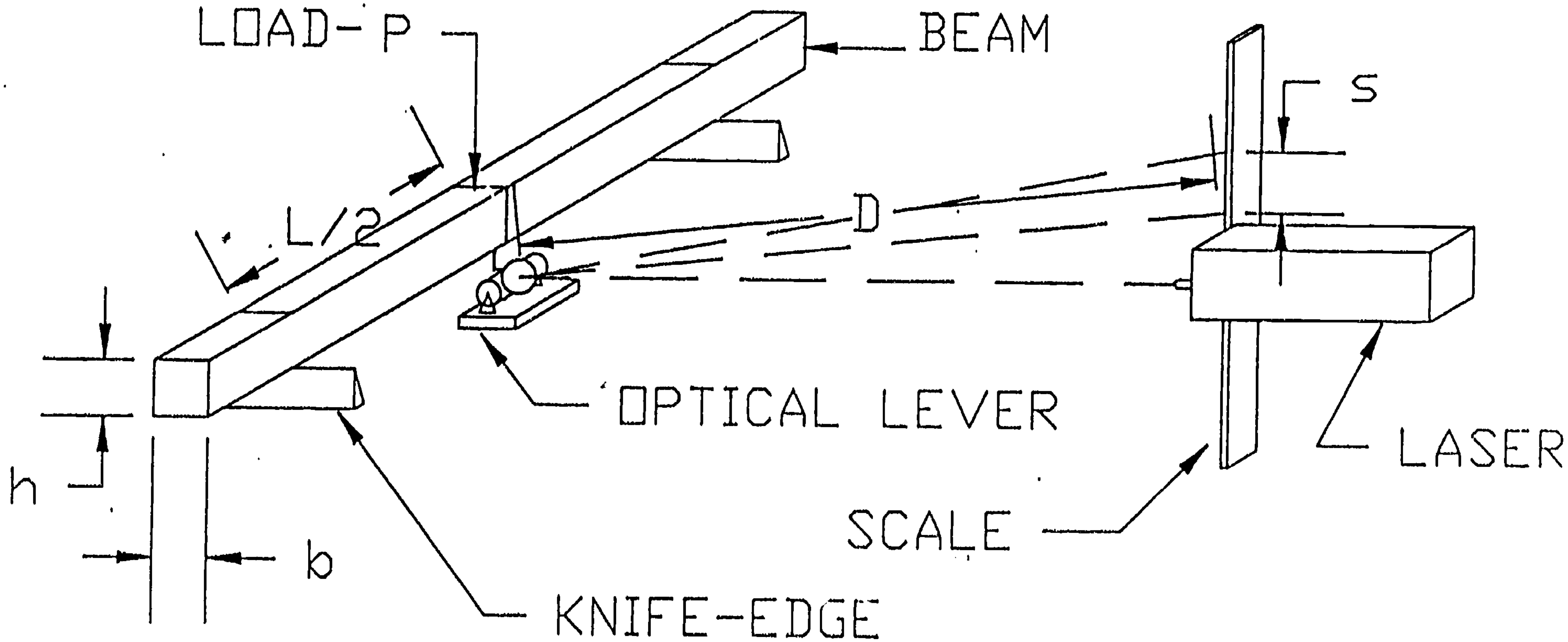
2. Place an initial load o[illegible] kg on the weight hanger. The weight hanger should be located exactly midway between the supports. The support points and the middle of the beam should be marked; the knife edge of the weight hanger should remain perpendicular to the edge of the beam throughout the experiment.

3. In this experiment, as the beam is loaded, the deflection of the beam rotates the optical lever by pushing on a small projection which is attached to the rotating cylinder. Make certain this proejction is located directly under the center of the beam and that it is making good contact with the beam. You may wish to flex the beam several times to make certain that the cylinder rotates freely.

4. Align the laser so the reflected beam strikes the measuring scale at the same level as the outgoing beam with the measuring scale located as close as possible to the laser.

5. Since the deflection of the beam is small, once again this becomes the critical measurement so you should check for consistent flexing of the beam by alternately placing and removing a 2 kg weight on the weight hanger. You should observe a consistent deflection of the laser ray on the measuring scale before proceeding.

SCHEMATIC-BEAM DEFLECTION APPARATUS



PROCEDURE: (continued)

6. If you are not absolutely certain that step 5 has not been completed satsifactorily, go back and recheck for consistent deflection of the reflected laser ray on the measuring scale. If you are unable to achieve consistency, your instructor may have additional suggestions. When step 5 has been completed, record the initial scale position with only the initial 1 kg load on the hanger.

7. Place a load on the weight hanger (any load from 1-6 kg that will produce a reasonable deflection). Record the deflected scale position.

8. Measure and record all other quantities in the data table and proceed to the calculations.

DATA:

P = ________ kg = ________ lb

L = ________ in

$E = 29.5 \times 10^6$ psi

x = ________ in

$I = x^4/12 =$ ________ in^4

r = ________ in

S_1 = initial scale reading = ________ cm

S_2 = final scale reading = ________ cm

$x = |S_2 - S_1| =$ ________ cm = ________ in

D = ________ in

CALCULATIONS:

Calculate the predicted deflection using formula 1 developed in the theory.

$d_{predicted}$ = ______ in

Determine the measured value of the deflection by using formula 2 given in the theory.

$d_{measured}$ = ______ in

RESULTS:

In this experiment it has been determined by the instructor that the equipment, if carefully used, is capable of results that are within ± 5%. Calculate the percentage of difference between the predicted and calculated values by taking the difference and comparing it to the predicted value.

$$\% \text{ difference} = \frac{\text{difference}}{\text{prediction}} \times 100 = \_\_\_\_\_\_ \%$$

CONCLUSIONS:

If the % difference you calculated falls within the capability of the equipment, make a statement about your results and the theory of the experiment. If the results are not within the capability of the equipment, make a logically correct statement about the outcome achieved compared to the theory.

SUMMARY QUESTIONS:

1. Of the list of variables that could be changed to affect the deflection of a beam, which was the only variable that was changed during this experiment?

2. By using the formula for beam deflection given in in the theory, by how much would the deflection of a beam change if you tripled the length between the support points?

3. If you had used a beam of the same width as you did in this experiment but only half the depth, by how much do you predict the deflection would change? (Hint. the moment of inertia = $\frac{bh^3}{12}$; first use $b = 1$ and $h = 2$; then use $b = 1$ and $h = 1$. Compare moments of inertia)

4. If you had used an aluminum beam instead of steel, how would the deflection have differed? Be specific by giving a numerical answer.

Pre-Module Survey

The purpose of this short survey is to help the instructor evaluate the overall success of this laboratory module. You will not be rated or graded in any manner and are not required to identify yourself by name.

1. Have you ever been enrolled in and completed a physics course prior to this year?

2. If your answer to 1 above was yes, approximately how many years ago did you take the physics course?

3. If you answer to 1 above was yes, was this physics course taken in:

   _____ High School

   _____ Technical School

   _____ College or University

4. If your answer to 1 above was yes, did the physics course include a laboratory component that was regularly scheduled (as opposed to an occasional lab activity)?

5. Check any of the statements that apply:

   _____ I have had an opportunity to visit an engineering industrial laboratory where materials properties are tested.

   _____ I have had an opportunity to visit an industrial or university laboratory where research is being conducted.

6. Can you name an area in which basic research in physics is being conducted today that will likely have an impact on technology in the next century?

7. Can you name two "high technology" applications of physics laboratory research that was done in the first half of this century?

Post-Module Survey

The purpose of this survey is to help the instructor to assess what the class has learned after completing the two lab exercises and to make changes to improve the exercises. You will not be rated or graded in any manner and are not required to identify yourself by name.

For each of the following questions rate the knowledge you have gained after completing the two lab exercises as follows:

A--if you feel you gained substantial new knowledge

C--if you feel you gained some new knowledge

F-- if you feel you gained little or no new knowledge

1. How much did you learn about the concept of elastic modulus?

   A C F

2. How much did you learn about the technique of indirect measurement?

   A C F

3. How much did you learn about the relationship between laboratory science and applied science?

   A C F

4. How much did you learn about the theory of beam flexure?

   A C F

5. How much did you learn about stating a conclusion based on laboratory results?

   A C F

6. How much did you learn about the way experimental and equipment design are related to theory?

   A C F

7. How much did you learn about the part that your skills depended on other persons in your lab group and class?

   A C F

Equipment Notes

For anyone reading this module wishing to use these lab exercises, the following are notes on equipment needs. No costs are given as they might vary depending on 'here equipment is purchased and how much improvising is done. Both of these labs are variations on a number of equipment options and the writer has tried various other options over a period of years; however, these exercises mark the first time that the writer has adapted the laser to both of these labs and it has been found that Fitch optical lever, which is an almost forgotten piece of equipment, was made to order for use with.the laser. The elastic modulus lab was formerly done with the optical lever and a small reading telescope which was difficult to focus due to the fact that the scale image was located behind the mirror. The laser has made this lab much easier for both instructor and student as it not only eliminates the focusing problem but at the same time eliminates the difficulty of scale resolution with the cross-hairs of the telescope. The same difficulties with the reliability of results still exist in measuring the elastic modulus of thin wires. The writer has not done research on this topic; however, would suggest that it would perhaps be instuctive to contact testing laboratories that may have had experience in this area. It was noticed, for example, that in trying the equipment with a sample of copper wire care needed to be taken in stabilizing the room temperature. During one trial a heating ur in the room was turned on and it resulted in the copper wi. retching an addititional amount that was significant wi..in a minute after the warm air began cirulating. No claims are made for the reliability of the results that are given; enough observations were made to <u>suggest</u> the following conjectures; First, the elastic modulus of a thin metal wire always seems to be much lower than typical reference source values for a bulk piece of the same metal. Second, the ratio of the modulii of wires made of two different metals was the same as the ratio of the modulii of bulk samples of the same metals; this has only been observed in the case of copper and steel and it is not felt that variables have been controlled well enough at this point to warrant anything but a conjecture. From an analysis of equipment used in the elastic modulus lab, the writer feels confident enough to report that when the elastic modulus of a certain material and a certain diameter is tested at a particular temperature, the results are reliable within ±10% which is quite often a rule of thumb goal for an introductory lab course. The beam deflection experiemnt results are much better using the optical lever and laser than any other technique the writer has attempted. The results obtained in the beam deflection lab are approximately ±5% and should be easily obtainable by students using a moderate amount of care. In fact, using the beam deflection apparatus in reverse to measure the elastic modulus of steel gives a result that compares very well with standard reference values.

Equipment Notes
(continued)

A. Elastic Modulus Equipment

1. Modulus of Elasticity apparatus (Central Scientific) comes equipped with following:

   a. Heavy support stand

   b. Fitch optical lever and mirror on clamp that mounts directly on support stand

   c. Several kinds of thin metal wire (steel and brass)

2. Laser: any low power unmodulated laser is acceptable

   a. Adjustable support stand optional but recommended; the writer improvised with a small rotating adjustable-height stool

   b. Ray-condensing lens (available in kit from Meterologic) This is highly recommended for improved scale resolution

3. Standard measuring equipment

   a. Meter stick, tape measure, vernier calipers, micrometer

   b. Micrometer--recommend reasonably good micrometer with .0001" vernier scale--wire diameter measurement can affect variation in final answer considerably, so care should be taken on this measurement.

4. Standard lab equipment

   a. Assorted stands and clamps

B. Beam Deflection Equipment

1. Lathe bed optical bench beam deflection apparatus (Central Scientific) comes with following equipment:

   a. Two different cross section steel bars for model beams

   b. Knife-edge beam supports

   c. Knife edge weight hanger; set of 1-2 kg weights not included

2. Lathe-bed optical bench and carriages for supporting beam (Central)

   a. Writer did not have this available when doing initial trials and was able to achieve good results by supporting the beam on heavy stands; however would have been nice to have and would have made set up much easier

3. Laser--same as above

4. Standard measuring equipment--same as above; no micrometer needed

5. Standard lab equipment--same as above

References and Other Printed Resources

The following is only a suggested list of resources for anyone wishing to incorporate the module exercises in their instruction. Almost any introductory technical physics text or statics and strength of materials text will contain the necessary theoretical background. In addition, many commercially available laboratory guides contain the labs as student exercises with many variations on equipment.

Technical Physics, James F. Sullivan, John Wiley and Sons, 1988, ISBN 0-471-04796-1

Technical Physics, Bigliani and Ferrigno, PWS-Kent, 1989,, ISBN 0-534-07686-6

Statics and Strength of Materials, Charles Harris, John Wiley and Sons, 1982, ISBN 0-471-08293-7

Introduction to Material Science for Engineers, James Shackelford, MacMillan, 1985, ISBN 0-02-409600-8

Young's Modulus of Elasticity-Measurement of Stretch with Optical Lever, Selected experiments in college physics, Catalog No. 71991, Suffix No. 92, page 378, Central Scientific Co. Catalog

Deflections of a Beam, Selected experiments in college physics, Catalog No 71991, Suffix No. 96, page 378, Central Scientific Co. Catalog

Sample Data and Results

Elastic Modulus Determination

The following two pages are the data and results on a trial of the elastic modulus equipment. This trial was done basically on a demonstration basis with a class taking data; however, students did assist in taking measurements to make it a somewhat realistic student trial of the equipment.

DATA:

Trial 1

Type of wire Steel

P = 2,000 g = 4.4 lb (1 g = .0022 lb)

L = 30.75 in

D = 100.25 in

r = .375 in

s = 13.5 cm = 5.31 in (1 cm = .3937 in)

d = diameter of wire = .0274 in

A = .7854(d²) = .00059 sq in

Trial 2

Type of wire Copper

P = 100 g = .22 lb

L = 30.63 in

D = 89.875 in

r = .375 in

s = 3.0 cm = 1.18 in

d = .0154 in

A = .00019 sq in

CALCULATIONS:

Calculate the value of E for both types of wire by using the working formula derived in the theory.

Trial 1

$$E_s = \frac{2PLD}{rsA}$$

$$= \frac{2 \times 4.4 \times 30.75 \times 100.25}{.375 \times 5.31 \times .00059} = 23.1 \times 10^6$$

$E_s =$ 23.1×10^6 lt/sq in

Trial 2

$$E_c = \frac{2PLD}{rsA}$$

$$= \frac{2 \times .22 \times 30.63 \times 89.875}{.375 \times 1.18 \times .00019} = 14.4 \times 10^6$$

$E_c =$ 14.4×10^6 lb/sq in

Ratio $\frac{E_s}{E_c} = 1.60$

Bulk Ratio $\frac{E_s}{E_c} = \frac{29.5}{18}$

1.63

Sample Data and Results

Beam Deflection Experiment

The following two pages is data and results from a trial of the beam deflection apparatus. Again, the trial was done as a class demonstration with students assisting in taking measurements.

DATA:

$P =$ 2.0 kg = 4.4 lb

$L =$ 35.44 in

$E = 29.5 \times 10^6$ psi

$x =$ .75 in

$I = x^4/12 =$ .026 in^4

$r =$ .375 in

S_1 = initial scale reading = ______ cm

S_2 = final scale reading = ______ cm

$x = |S_2 - S_1| =$ 7.30 cm = 2.875 in

$D =$ .107 in

CALCULATIONS:

Calculate the predicted deflection using formula 1 developed in the theory.

$$d_p = \frac{PL^3}{48EI}$$

$$= \frac{4.4 \times (35.44)^3}{48 \times 29.5 \times 10^6 \times .026} = .0053''$$

$d_{predicted}$ = .0053 in

Determine the measured value of the deflection by using formula 2 given in the theory.

$$d_m = \frac{rS}{2D}$$

$$= \frac{.375 \times 2.875}{2 \times 107} =$$

$d_{measured}$ = .0050 in

RESULTS:

In this experiment it has been determined by the instructor that the equipment, if carefully used, is capable of results that are within ± 5%. Calculate the percentage of difference between the predicted and calculated values by taking the difference and comparing it to the predicted value.

$$\% \text{ difference} = \frac{\text{difference}}{\text{prediction}} \times 100 = 5.7\ \%$$

$$= \frac{.0003}{.0053} \times 100 = 5.7\%$$